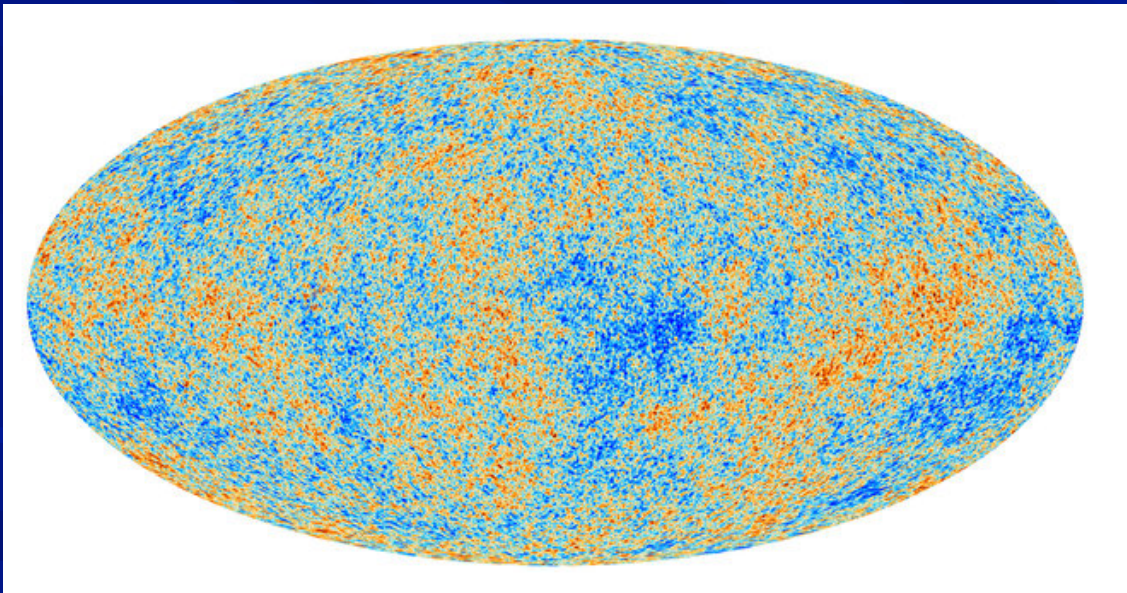
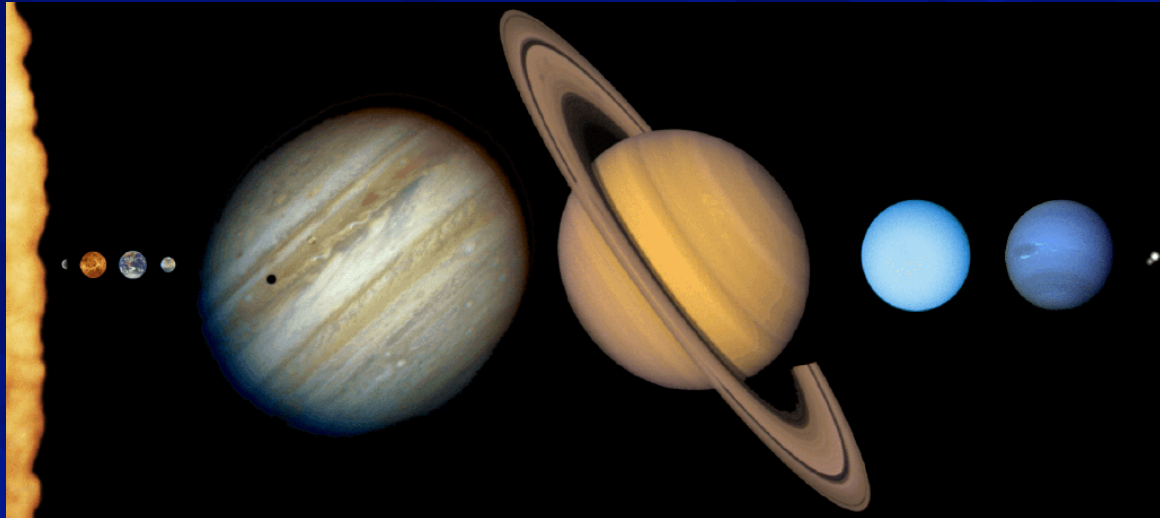


# The Modern Origins Story: From the Big Bang to Habitable Planets

Eliot Quataert  
(UC Berkeley)

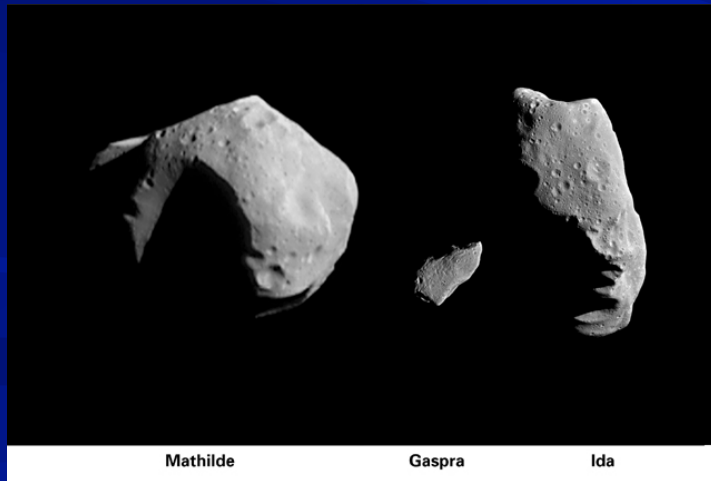


# The Solar System



Age  $\approx$  4.5 Gyrs

8 (9? 10? 12?) planets orbiting the sun all in roughly the same plane



Lots of rocks & debris left over from formation of solar system  
 $\Rightarrow$  asteroids, comets, craters on moon, extinction of dinosaurs, ...

# Our Own Milky Way Galaxy

Scale: Size of Solar System: 0.01 light-years  
Typical Distance btw. Stars: few light-years



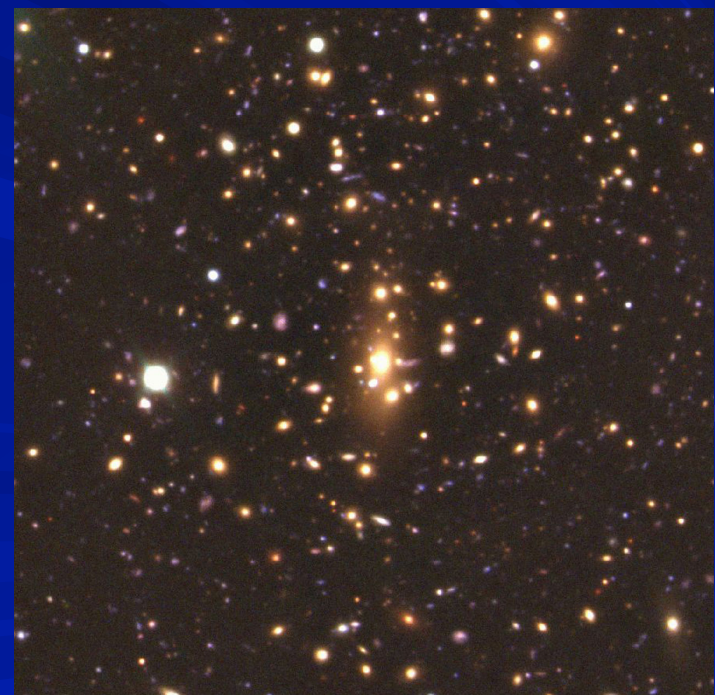
Size of Galaxy ~ 100,000 light-years  
~ 100 billion stars (and planets); weighs ~ trillion  $M_{\text{sun}}$   
most of the mass **“dark” -- not stars, gas, etc.**  
– detected via gravity, not light

# Other Galaxies



Andromeda: Closest large  
Galaxy to Milky Way  
 $\approx$  3 million light-years away

Galaxies generally found  
In bound collections  
– “groups” or “clusters” –  
with 10s-1000s of members  
(true for Milky Way as well)

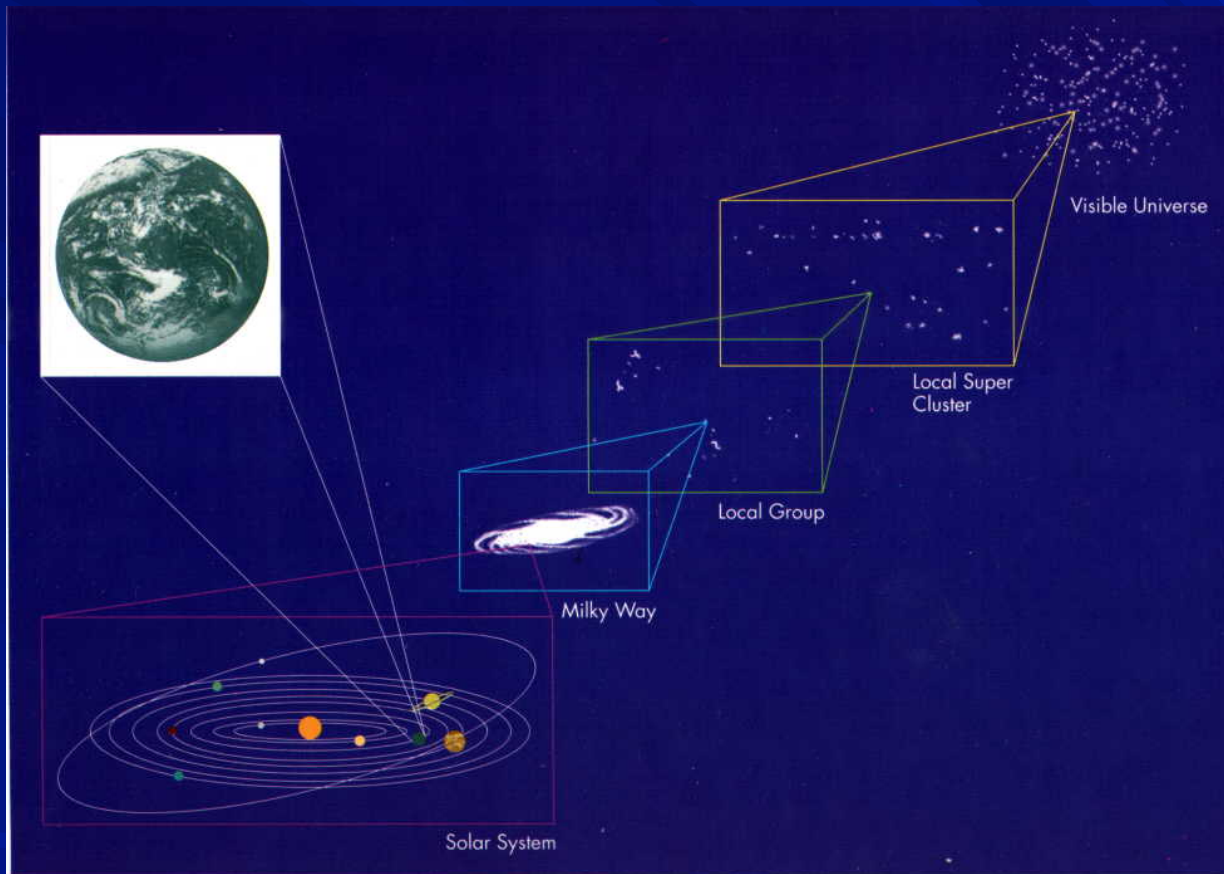


# A Cosmic Census

*Who are we?*

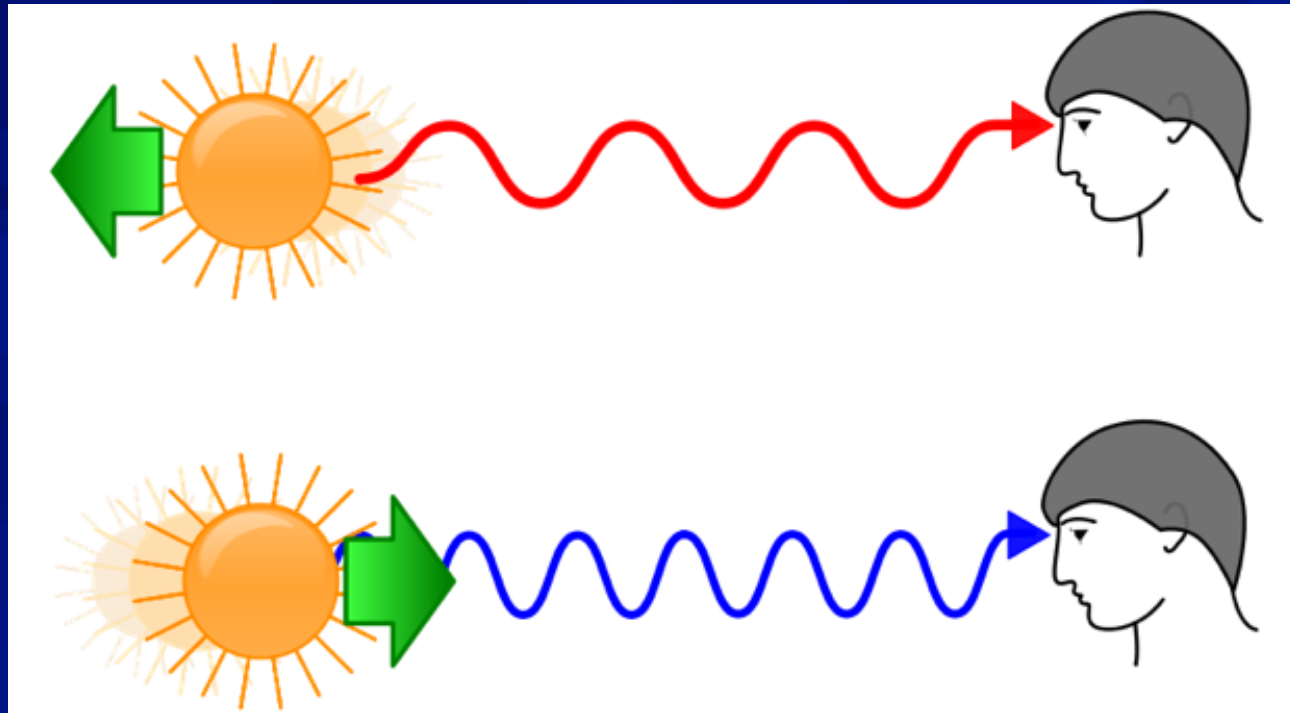
Far out in the uncharted backwaters of the unfashionable end of the Western Spiral arm of the Galaxy lies a small unregarded yellow sun. Orbiting this at a distance of roughly ninety-eight million miles is an utterly insignificant little blue-green planet whose ape-descended life forms are so amazingly primitive that they still think digital watches [I pods] are a pretty neat idea.

*Douglas Adams*



For all our conceits about being the center of the universe, we live on a routine planet of a humdrum star stuck away in an obscure corner on an unexceptional galaxy which is one of about 100 billion galaxies. That is the fundamental fact of the universe we inhabit, and it is very good for us to understand that. *Carl Sagan*

# Facts About Light



## 'Redshift'

Light we see  
encodes speed  
of objects  
relative to us

## Distant Objects Tell us the History of the Universe

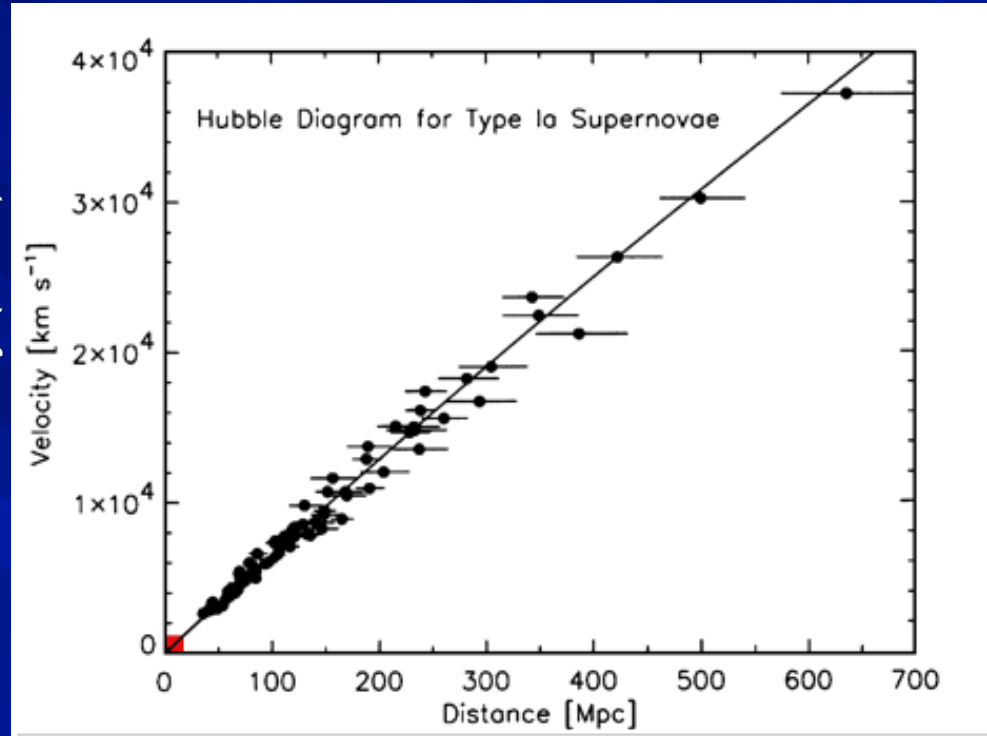
Speed of Light ~ 1 billion miles/hr  
~ 1 circumference of Earth in 0.1 sec

# The Expansion of the Universe



Discovered by Hubble 1929

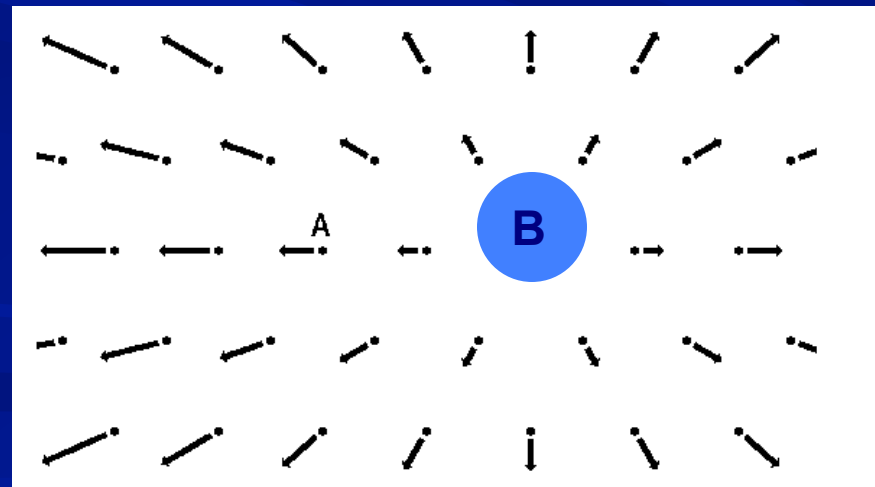
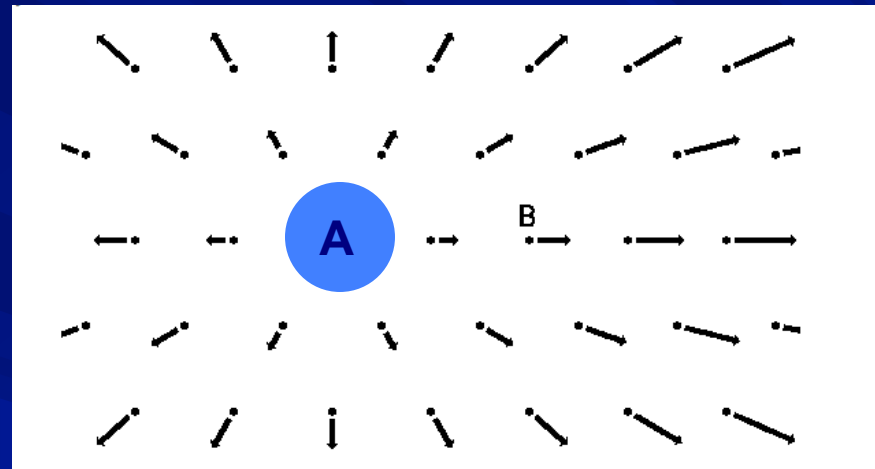
Velocity (km/s)



Distance From Earth (Millions Light Years)

# Copernican Principle: We are not special

(not our solar system, galaxy, visible universe, stuff we are made of ....)



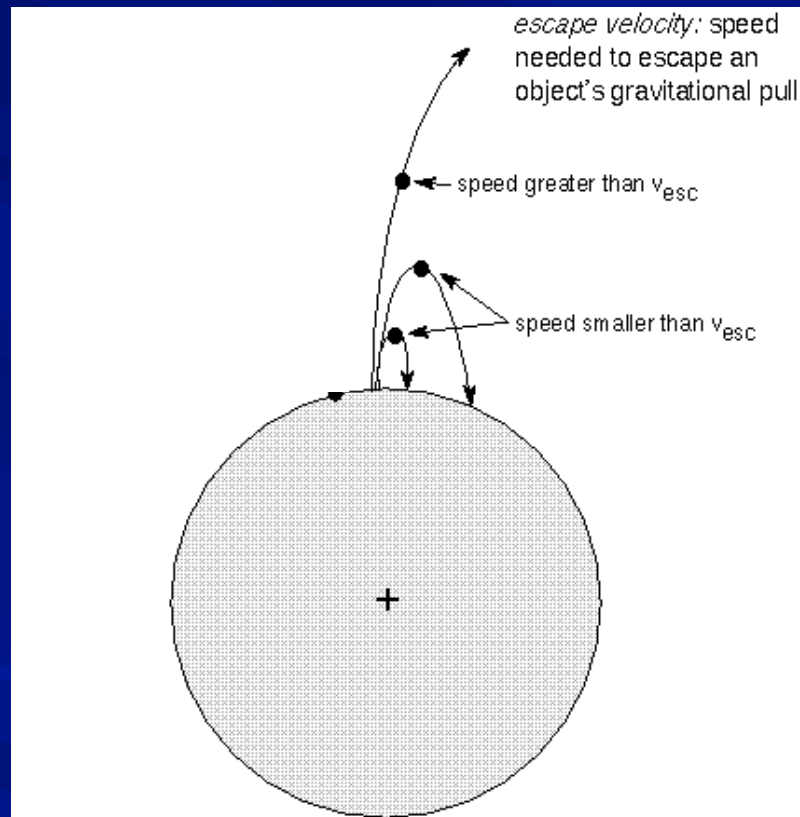
Expansion Viewed  
From Two Diff  
Galaxies (A & B)  
Is the Same!

Courtesy Ned Wright

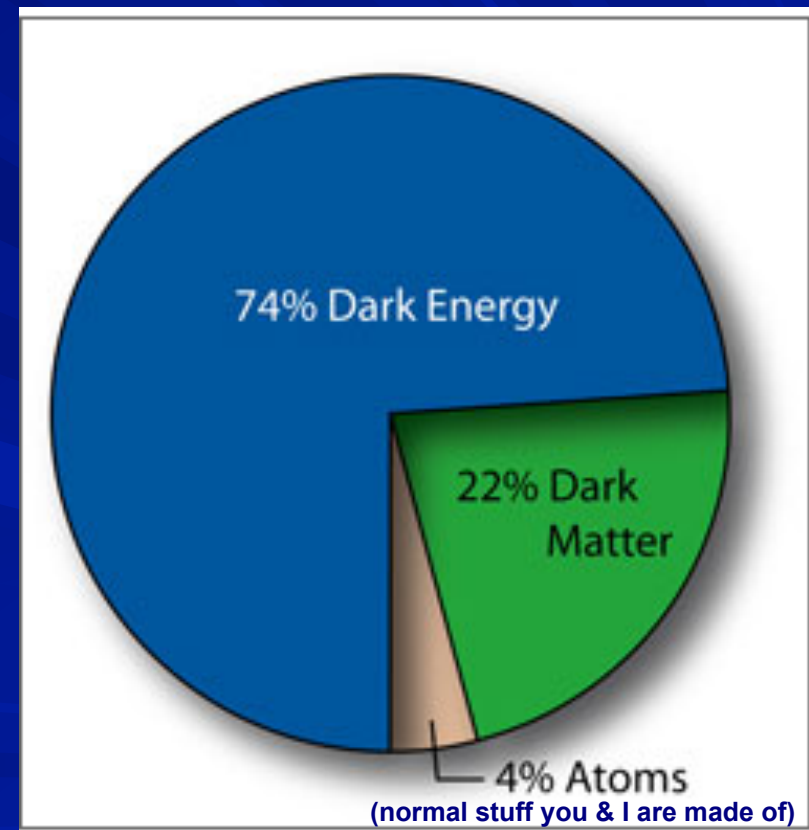
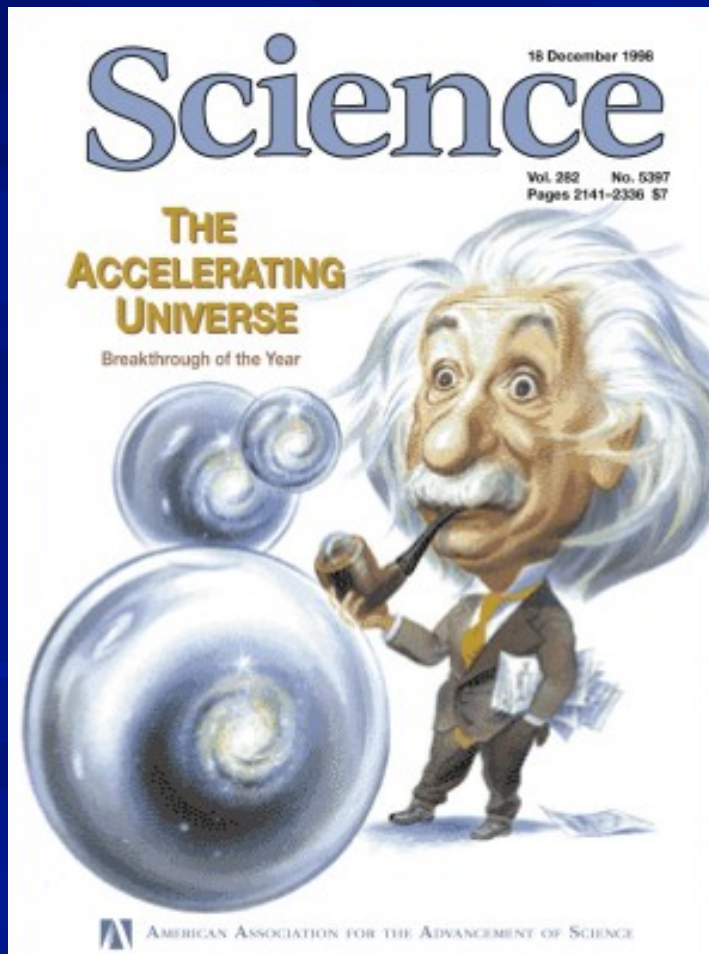
Everything is expanding away from everything else



# The Expansion of the Universe Should Be Slowing Down ...



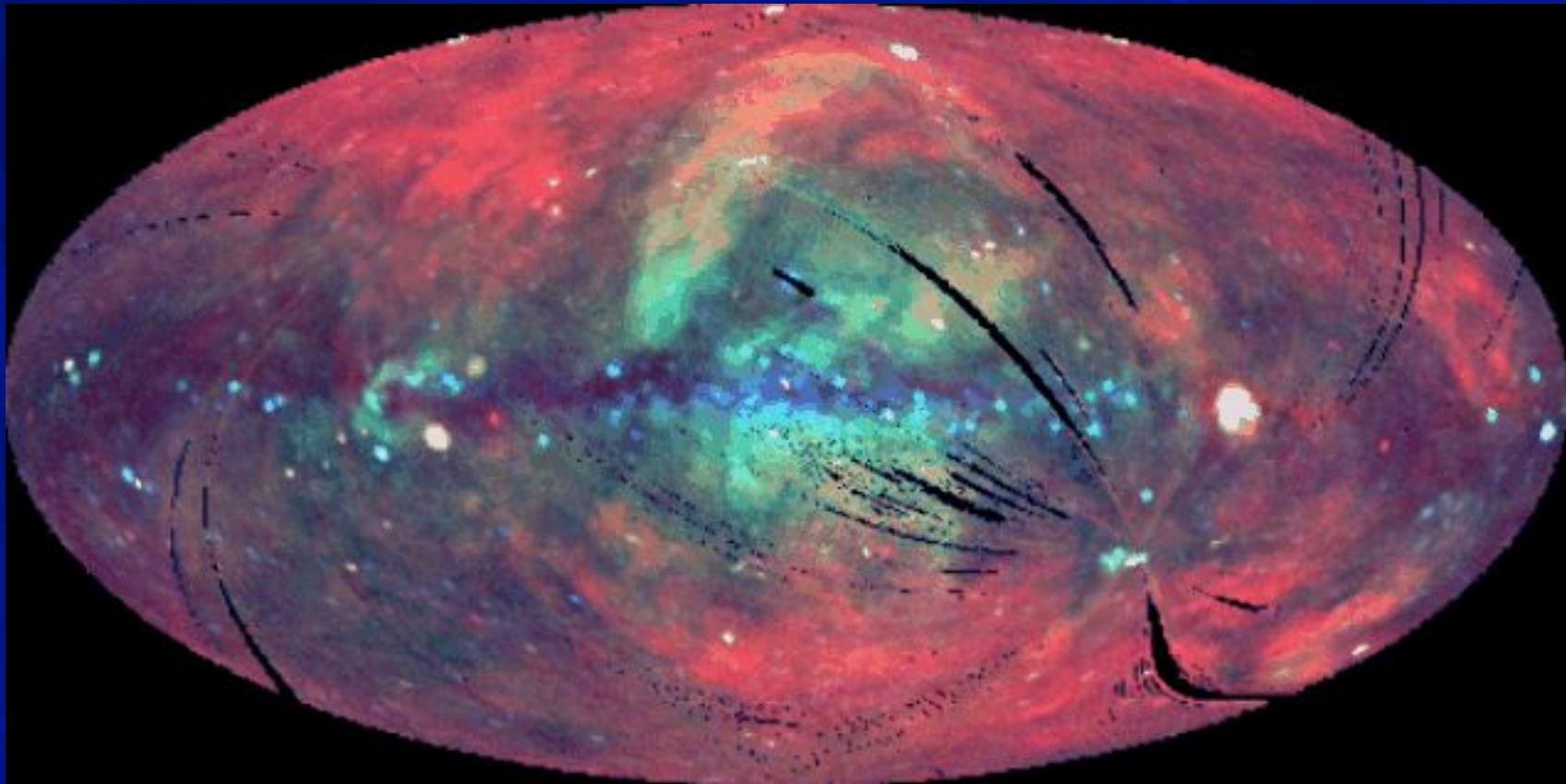
# But it's Not! The Expansion is Accelerating ...



Requires that most of Mass/Energy in universe is some weird "dark energy" we don't understand

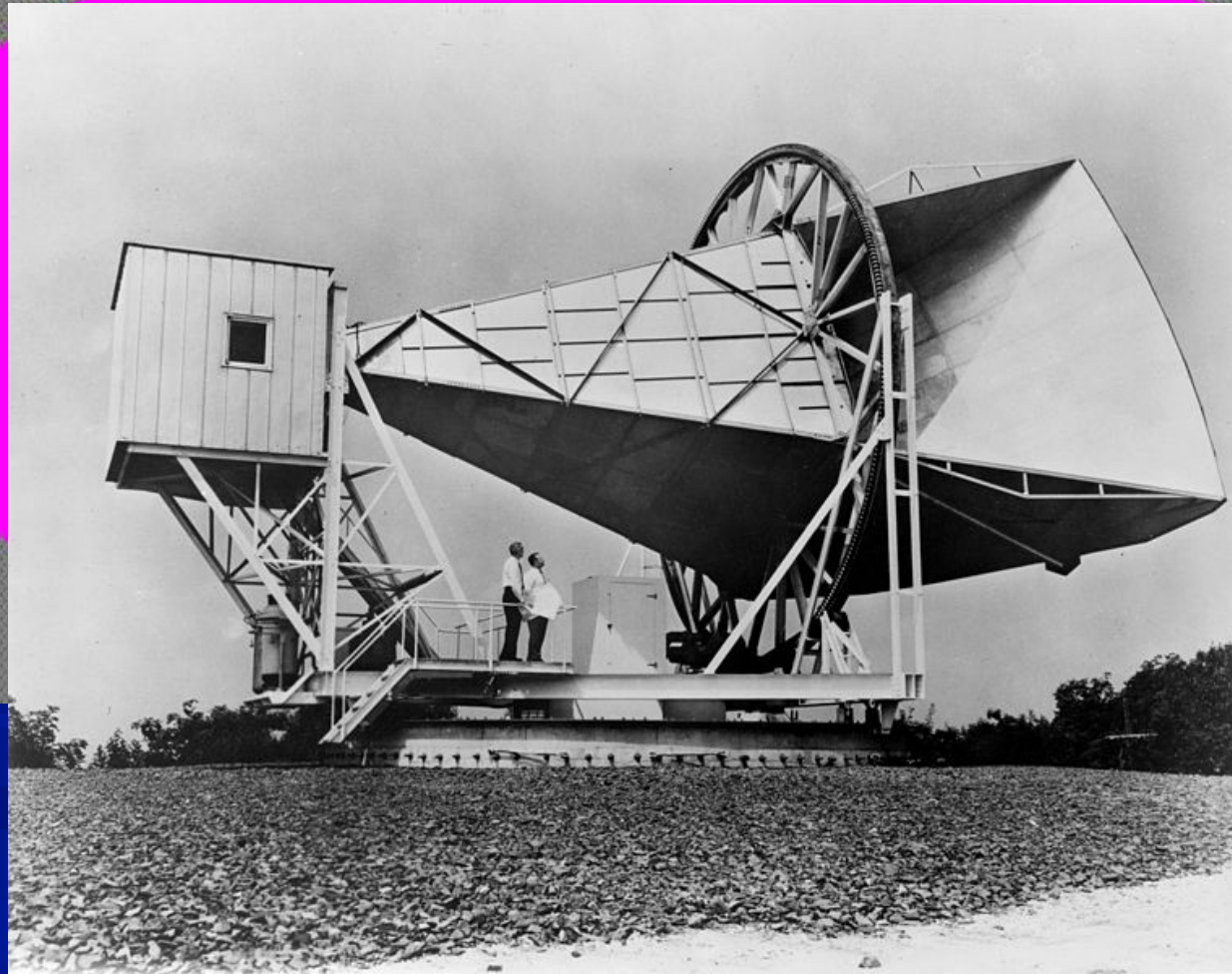


The Milky Way Galaxy



The X-ray Sky

The Sky in Every Direction Glows in Microwave Light  
(2.73 Kelvin = -454.8° F !)

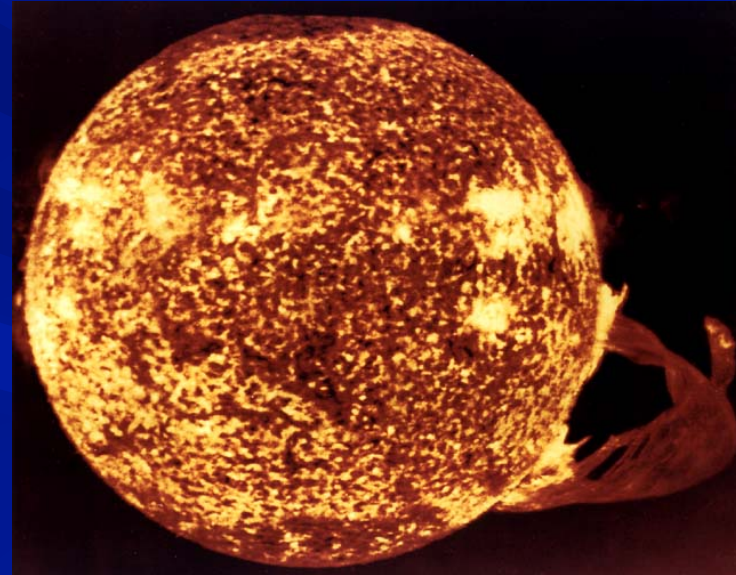


Penzias & Wilson 1965

Microwave Glow  
Was Predicted Given  
Expansion of Universe



Expansion → In the past  
everything closer together  
→ denser & hotter → light!

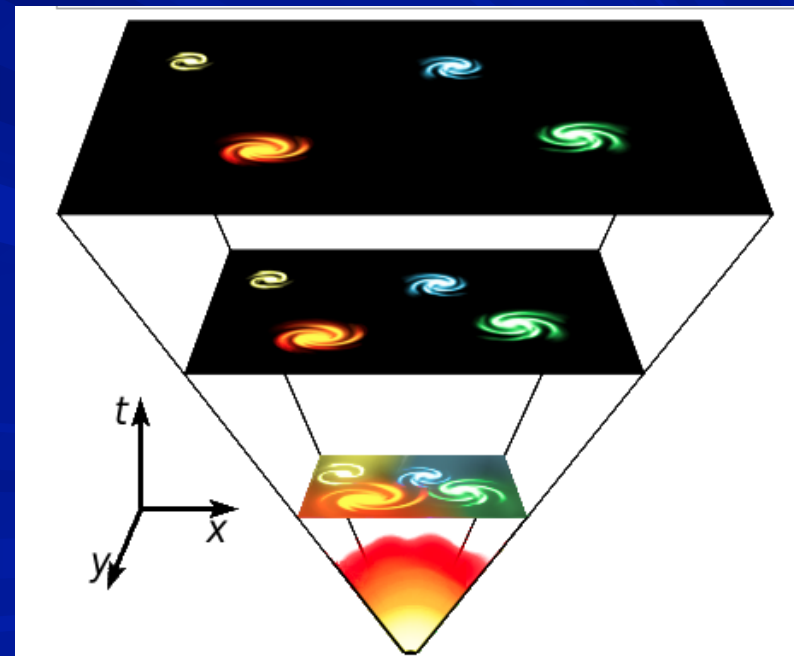


# The “Big Bang”

(i.e., the beginning as we know it)

- Extrapolating expansion back, Universe was arbitrarily dense and hot **13.8 Billion** years ago
  - **Physics as we know it breaks down**

Not an Explosion at a Place  
There is no Center  
The Universe may have been  
Infinitely Large Even at the Big Bang



# Three Pillars of Evidence for Big Bang

- ✓ Expansion of Universe
- ✓ Microwave Background Radiation
- Origin of Hydrogen and Helium in the Universe
  - 74% Hydrogen, 24% Helium, 2% heavy elements (O, C, Fe, ...)
  - Universe initially a soup of fundamental particles, H & He formed ~3 minutes after Big Bang. Everything else forms later in stars

Periodic Table of the Elements

1	IA	1	H	2	O	2	He																														
2	IIA	3	Li	4	Be	5	B	6	C	7	N	8	O	9	F	10	Ne																				
3	IIIB	11	Na	12	Mg	13	Al	14	Si	15	P	16	S	17	Cl	18	Ar																				
4	IVB	19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr
5	VB	37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe
6	VIB	55	Cs	56	Ba	57	*La	72	Hf	73	Ta	74	W	75	Re	76	Os	77	Ir	78	Pt	79	Au	80	Hg	81	Tl	82	Pb	83	Bi	84	Po	85	At	86	Rn
7	VII	87	Fr	88	Ra	89	+Ac	104	Rf	105	Ha	106	Sg	107	Ns	108	Hs	109	Mt	110	110	111	111	112	112	113	113										

\* Lanthanide Series

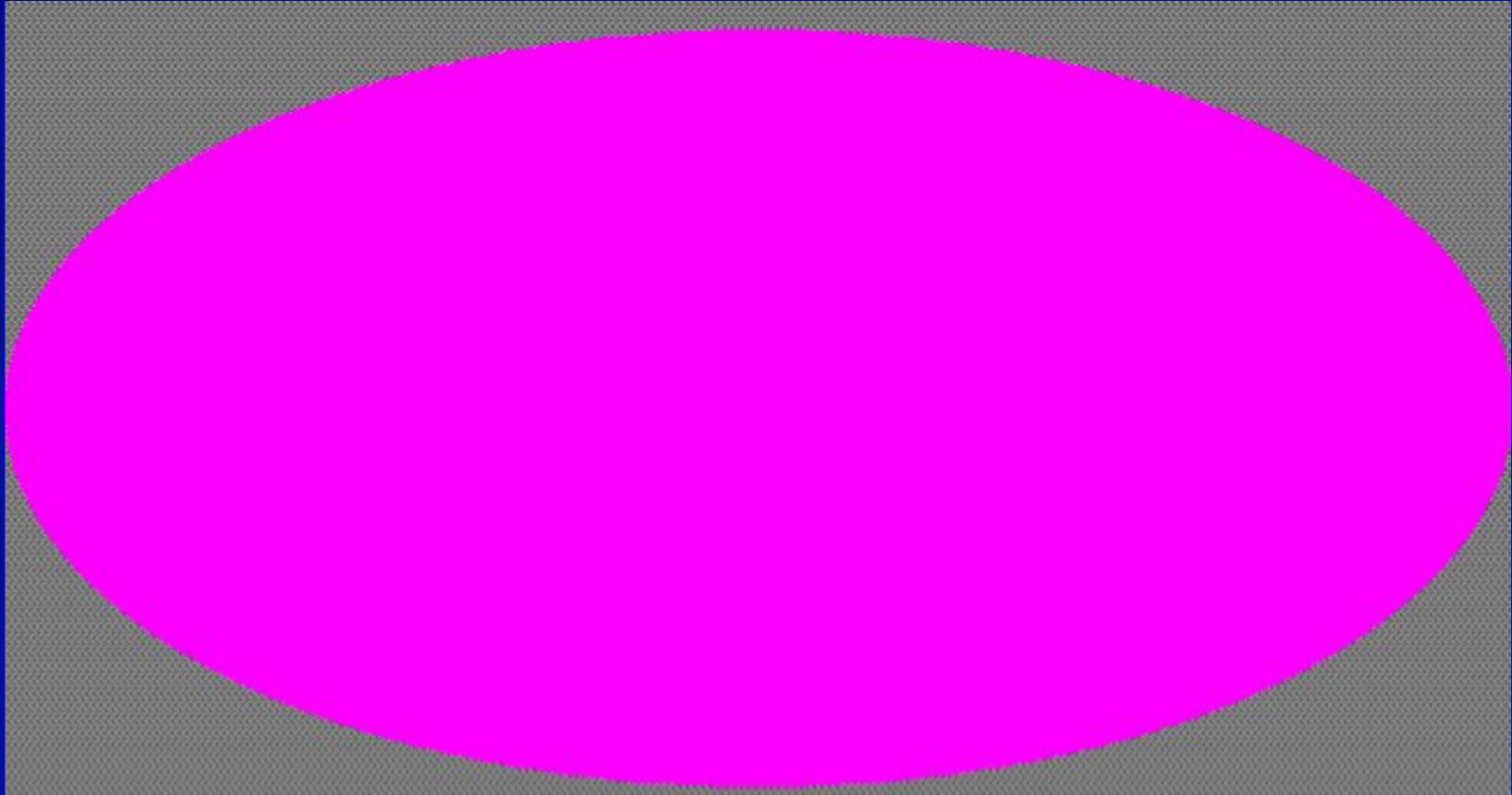
58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

+ Actinide Series

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

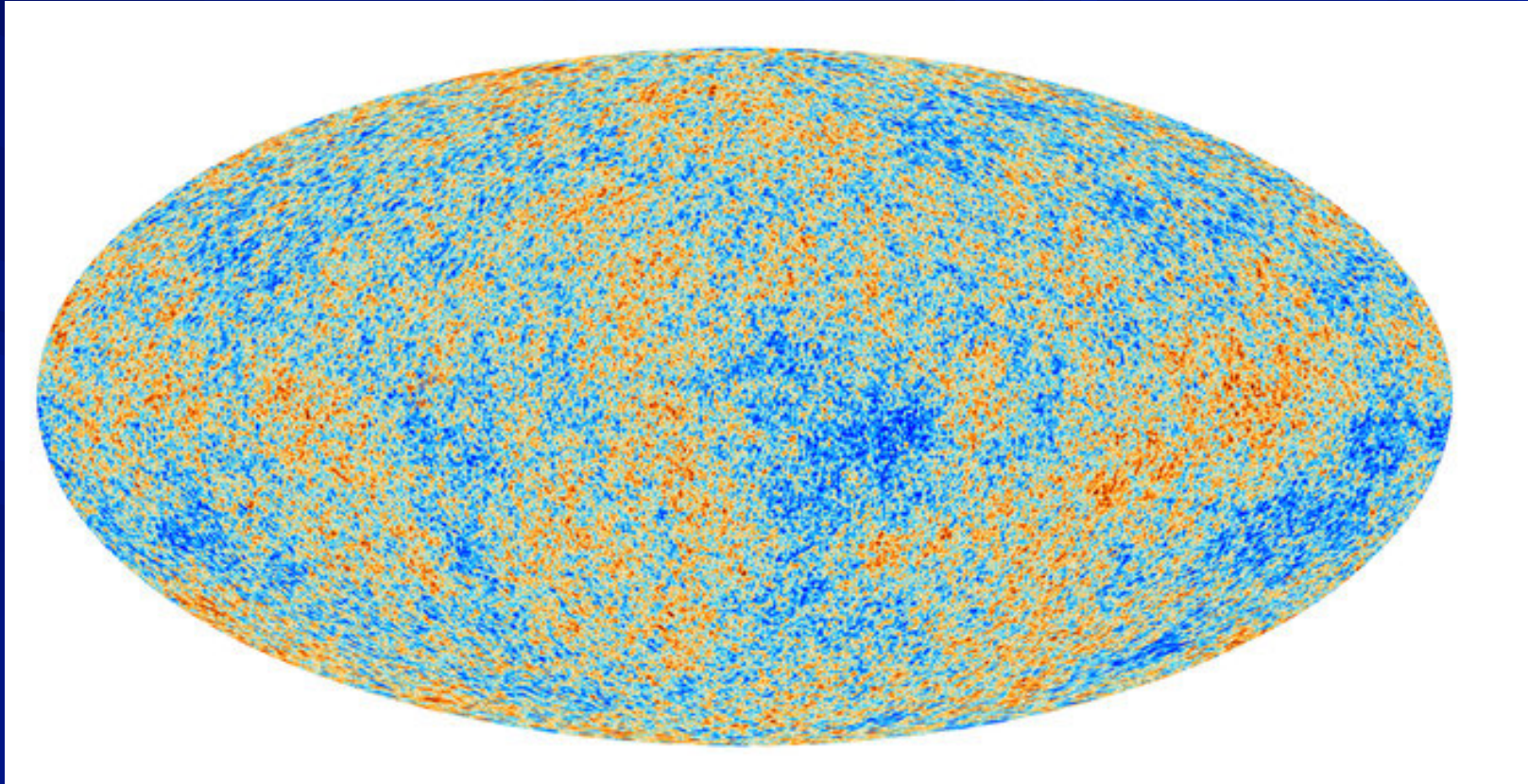


## The Sky in Every Direction Glows in Microwave Light



The Infant Universe Looks Nearly the Same in Every Direction

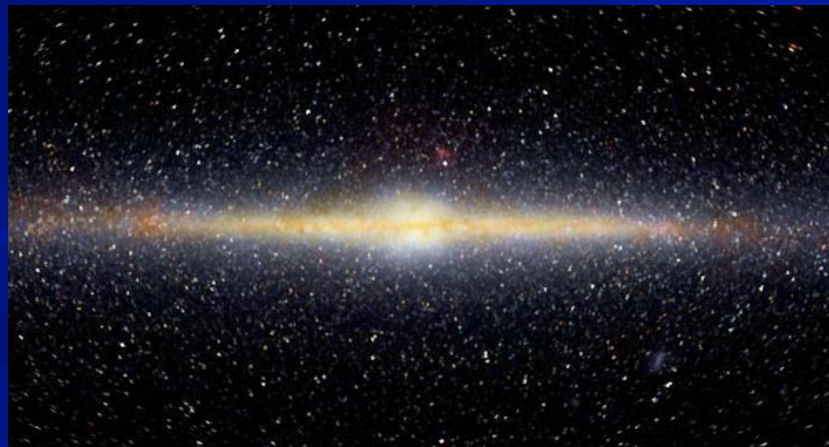
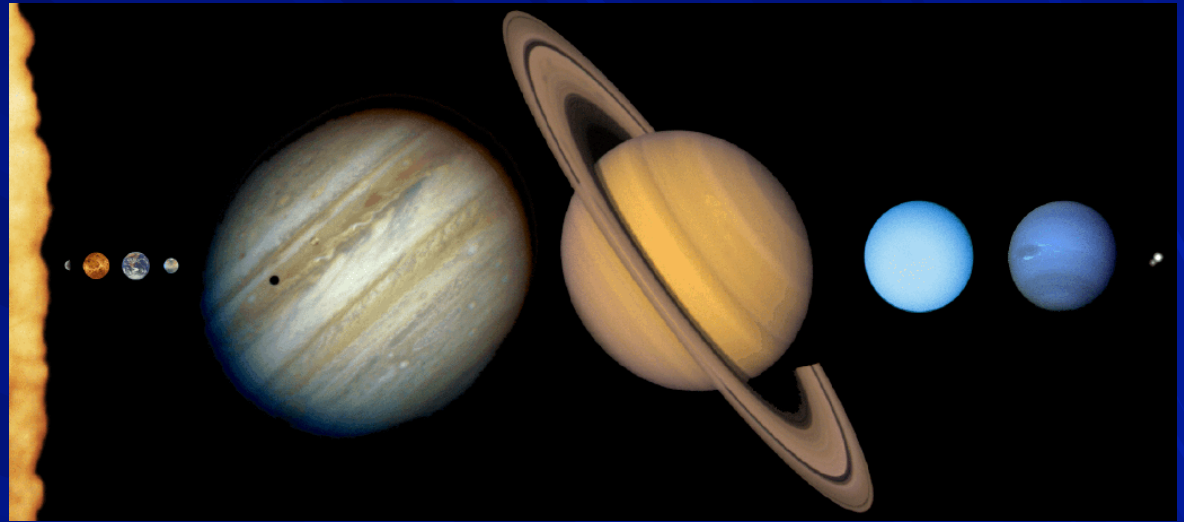
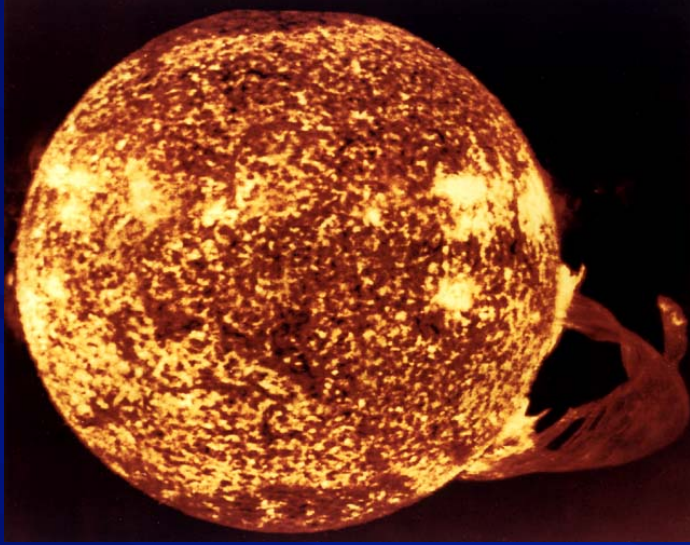
## The Sky in Every Direction Glows in Microwave Light



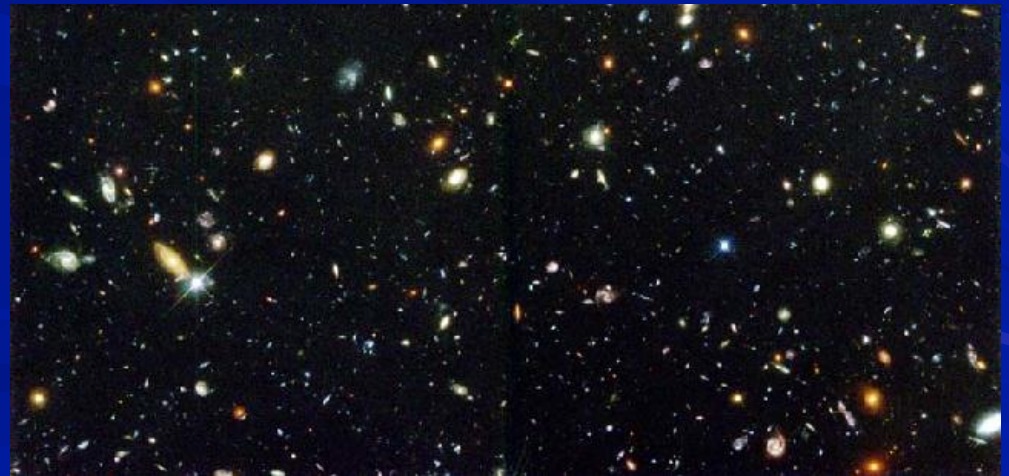
Smooth Early Universe Observed Today in the Microwave Sky

Differences in Microwave Light on Sky due to  
Tiny  $\sim 0.001\%$  differences in temperature/density  
from one part of the infant universe to another

# The Lumpy Universe Today



The Milky Way Galaxy



The Hubble Deep Field

# Matter Clumps Via Gravity

$z = 20.0$

White = dense  
Blue = underdense

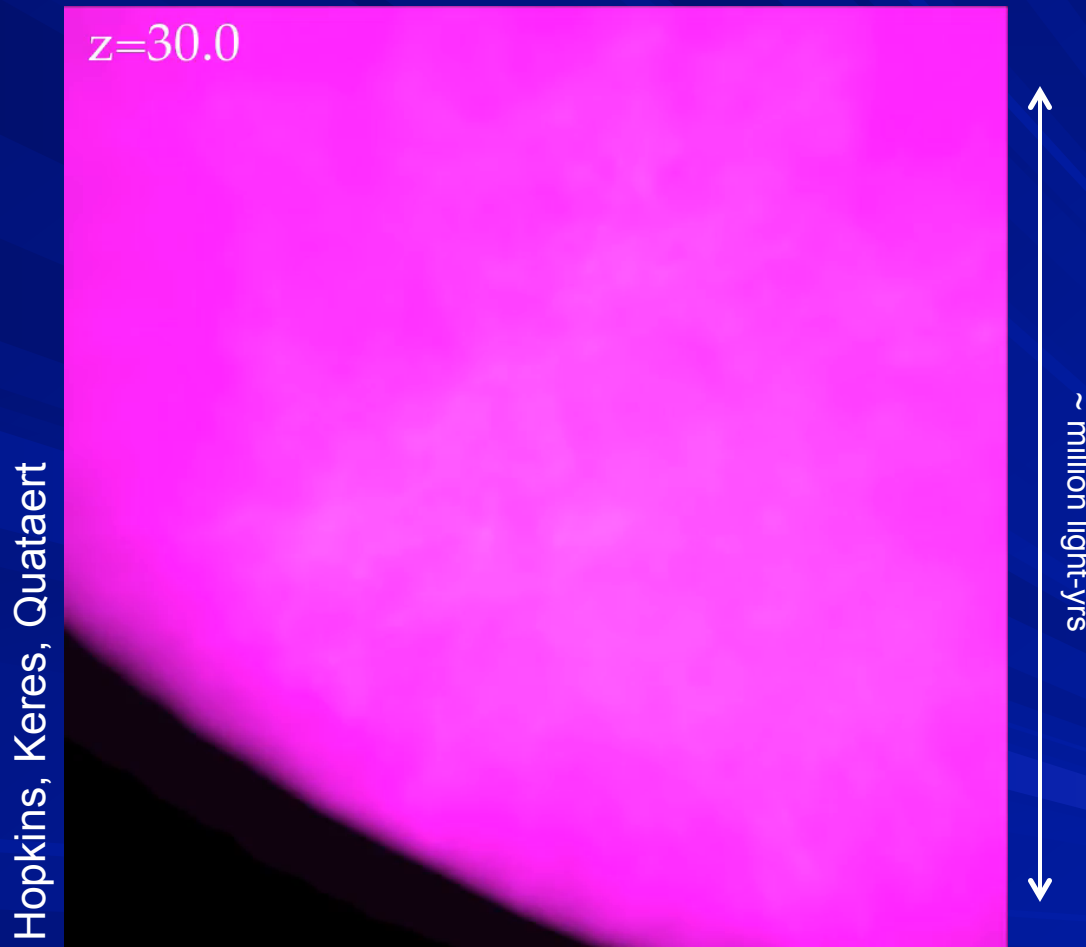
Regions denser than average get denser and more massive due to relentless inward pull of gravity (even though universe is expanding!)

200  $10^6$  light-yrs  
50 Mpc/h

(Credit: Volker Springel)

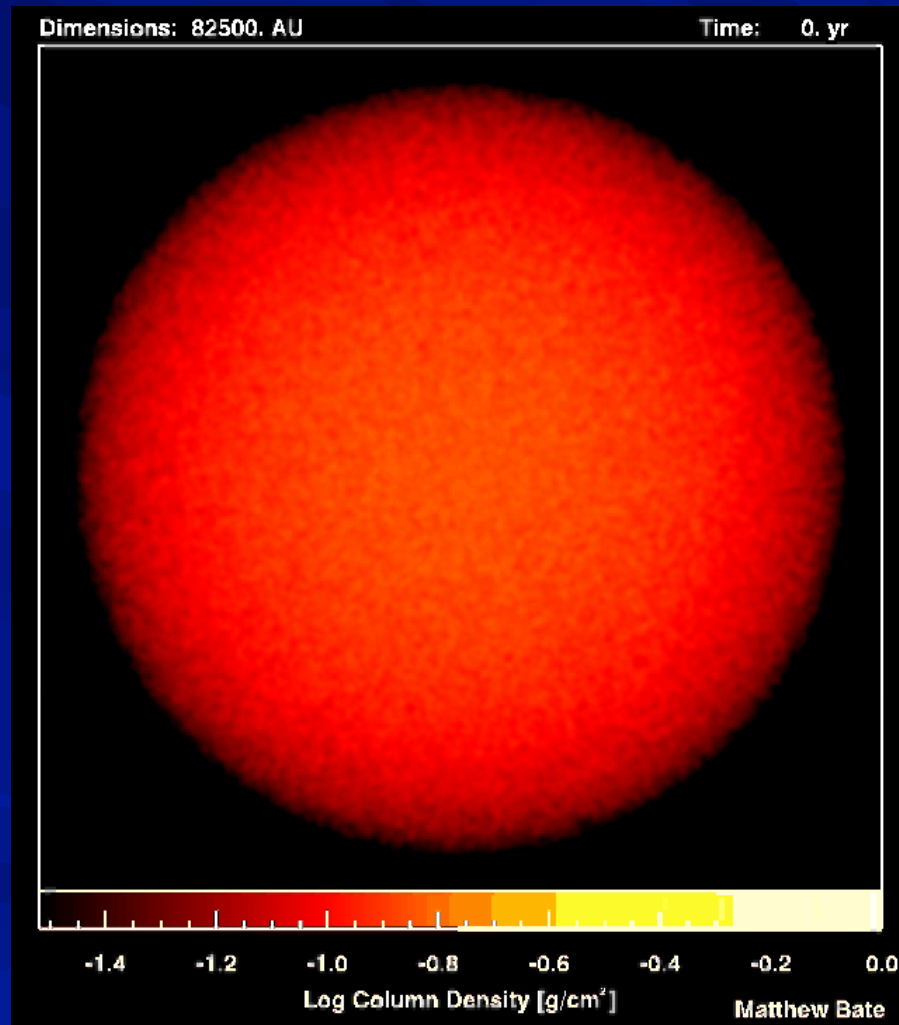
Simulation of Dark Matter from 200 million yrs after Big Bang to present  
Regions grow until held together by their own gravity

# Gas Flows into (and out of) Galaxies



Simulation of a Region that will become a Milky Way-like Galaxy  
with Models for how Star Formation Impacts Surrounding Gas

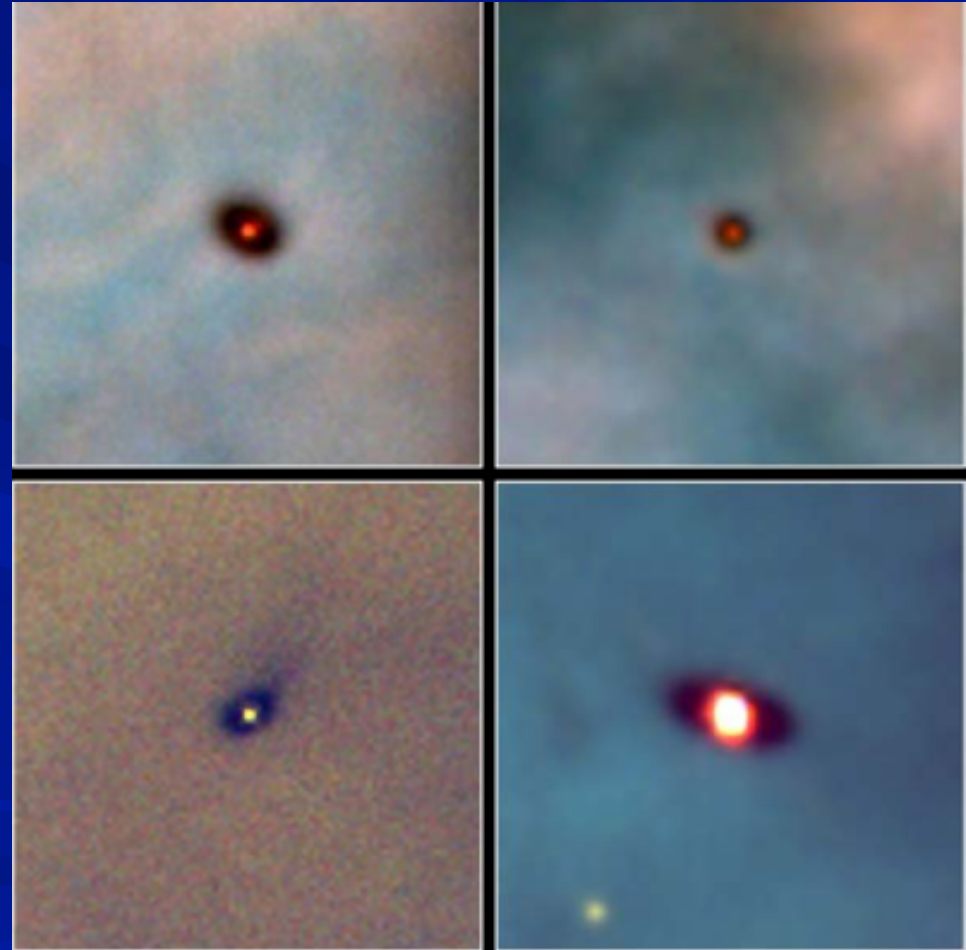
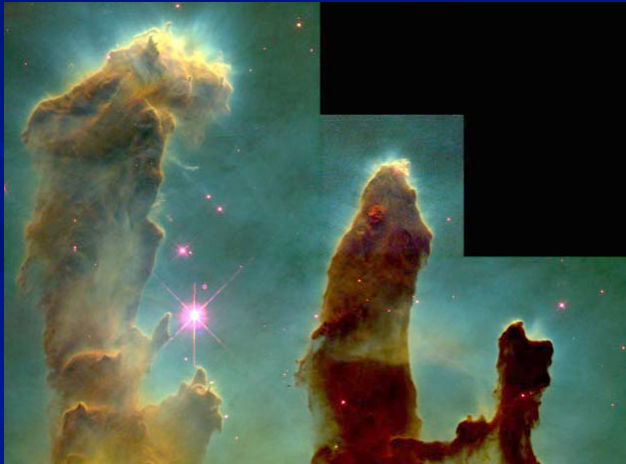
# Once Inside Galaxies, Gas Collapses Yet Again to Form Stars & Planets



Simulation of Collapse of Gas Cloud to Form Stars (Matthew Bate)

# Once Inside Galaxies, Gas Collapses Yet Again to Form Stars & Planets

Observations of Stellar Birth



Planet-Forming Disks Around Young Stars

# Towards Habitable Planets

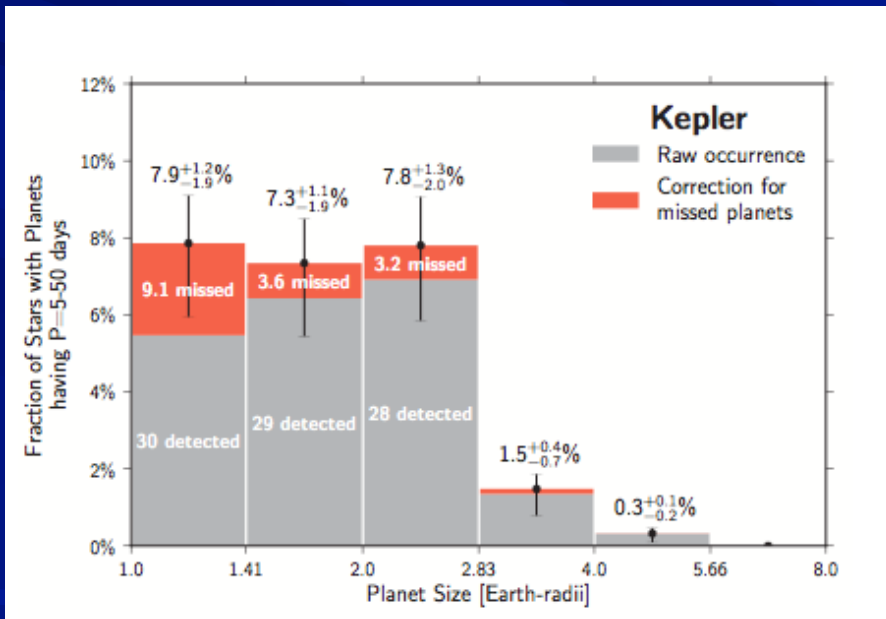


[www.eso.org](http://www.eso.org)



# Towards Habitable Planets

at least ~10% of stars have Planets 1-2x size of Earth



UCB undergrad & grad student Erik Petigura

## Two Promising Places to Live, 1,200 Light-Years From Earth

By DENNIS OVERBYE



American Association for the Advancement of Science

An artist's impression of a sunrise on Kepler 62f. The two outer planets of the Kepler 62 system may lie in the habitable zone, where liquid water could exist on the surface.

New York Times

~3000 planets discovered around other stars (Kepler)

# The Frontiers of our Current Scientific Understanding

- Why is the expansion of the Universe accelerating & what is its ultimate fate?
- What came before the Big Bang?
- Why does the Universe have properties conducive to carbon-based life forms like us?
- How common is life? “Intelligent” life?

